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A Way to Measure Polarized Gluon Distributions †

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Abstract

Effects of the spin–dependent gluon distributions on J/ψ productions in polarized ep and pp collisions are investigated. These productions serve as a very clean probe of the spin–dependent gluon distributions in a proton.

There have been several theoretical approaches to get rid of *so–called* the "proton spin crisis"[1, 2]. Among them, there is an interesting idea that gluons contribute significantly to the proton spin through the $U_A(1)$ anomaly[3]. In this description the first moment of the spin–dependent gluon distribution ($\Delta G(Q^2)$) inside a proton is as large as $5 \sim 6$ at $Q_0^2 = 10.7\mathrm{GeV}^2$(EMC value) and concomitantly the amount of the proton spin carried by quarks does not necessarily become small. However, is the polarized gluon contribution really so large in a proton? In order to confirm this, it is absolutely necessary to measure, in experiments, the physical quantities which are sensitive to the magnitude of spin–dependent gluon distribution.

In the present work, we study two interesting processes which predominantly depend on the spin–dependent gluon distributions : one is the J/ψ production in polarized proton–polarized proton collisions and the other is the inelastic J/ψ production in polarized electron–polarized

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proton collisions [4]. In order to discuss how these processes are affected by spin–dependent gluon distributions, we take the following three different types of $x\delta G(x)$:

(a) our model [5] ;

$$x\delta G(x, Q^2 = 10.7\text{GeV}^2) = 3.1x^{0.1}(1-x)^{17} \text{ then} \tag{1}$$
$$\Delta G(Q^2_{EMC}) = 6.32 \ .$$

(b) Cheng–Lai type model [6] ;

$$x\delta G(x, Q^2 = 10\text{GeV}^2) = 3.34x^{0.31}(1-x)^{5.06}(1-0.177x) \text{ then} \tag{2}$$
$$\Delta G(Q^2_{EMC}) = 5.64 \ .$$

(c) no gluon polarization model [6] ;

$$x\delta G(x, Q^2 = 10\text{GeV}^2) = 0 \ \text{ then } \ \Delta G(Q^2_{EMC}) = 0 \ . \tag{3}$$

The behavior of $x\delta G(x, Q^2)$ and $\delta G(x, Q^2)/G(x, Q^2)$ are depicted in Fig.1 (A) and (B) as a function of x, respectively. As shown here, the $x\delta G(x)$ of type (a) has a sharp peak at $x < 0.01$ and rapidly decreases with increasing x while that of (b) has a peak at $x \approx 0.05$ and gradually decreases with x. The shape of $x\delta G(x)$ taken by many authors[7] is almost the same as that of type (b).

First, we discuss the inclusive J/ψ production in polarized proton–polarized proton collisions. Since the J/ψ productions come out only via gluon–gluon fusion processes at the lowest order of QCD diagrams, those cross sections are sensitive to the spin–dependent gluon distribution in a proton. Let us define the two–spin asymmetry $A_{LL}^{J/\psi}(pp)$ for this process by

$$A_{LL}^{J/\psi}(pp) = \frac{[d\sigma(p_+p_+ \to J/\psi\ X) - d\sigma(p_+p_- \to J/\psi\ X)]}{[d\sigma(p_+p_+ \to J/\psi\ X) + d\sigma(p_+p_- \to J/\psi\ X)]} = \frac{Ed\Delta\sigma/d^3p}{Ed\sigma/d^3p} \ , \tag{4}$$

where $p_+(p_-)$ denotes that the helicity of a proton is positive (negative). In eq.(4), the numerator (denominator) represents the spin–dependent (spin–independent) differential cross section for the hard–scattering parton model and is formulated in the framework of perturbative QCD[8]. For estimation of $A_{LL}^{J/\psi}(pp)$, we take the spin–dependent gluon distributions (a), (b)

and (c) given by eqs.(1), (2) and (3). Setting $\theta = 90^\circ$ (θ is the production angle of J/ψ in the CMS of colliding protons) and using the spin–independent gluon distribution function of the DO parametrization [9] for (a), and the DFLM parametrization [10] for (b) and (c), we have calculated $A_{LL}^{J/\psi}(pp)$ for several choices of Q^2 ; $Q^2 = m_{J/\psi}^2 + p_T^2$, $4p_T^2$, $(\hat{s}\hat{t}\hat{u})^{1/3}$, $-\hat{t}$ and so on. We see that $A_{LL}^{J/\psi}(pp)$ for each type of the spin–dependent gluon distributions is insensitive to the choice of Q^2. Thus, we here take $Q^2 = m_{J/\psi}^2 + p_T^2$ by taking the mass effect of the J/ψ particle into account. The results of $A_{LL}^{J/\psi}(pp)$ are shown in Fig.2 as a function of p_T of the J/ψ at (A) $\sqrt{s} = 20$ and (B) 100 GeV. At $\sqrt{s} = 20$ GeV our largely polarized gluon distribution, (a), contributes little to $A_{LL}^{J/\psi}(pp)$ in all p_T regions because the region near the peak of $x\delta G(x)$ is kinematically cut. The $A_{LL}^{J/\psi}$ predicted with type (a) is not so significantly different from that with no gluon polarization (type (c)), and it is practically difficult to find the difference between them. However, for higher energies such as $\sqrt{s} = 100$ GeV, we might distinguish types (a) from (c) for spin–dependent gluon distributions by choosing a moderate p_T region. In addition, one can see that the behavior of $A_{LL}^{J/\psi}$ for type (b) largely differs from those for types (a) and (c) at $\sqrt{s} = 20$ and 100 GeV. Therefore, it is expected that one can either rule out or confirm type (b) by measuring $A_{LL}^{J/\psi}$.

Next, in order to distinguish types (a) from (c) of $x\delta G$, we consider inelastic J/ψ productions in polarized ep collisions [4]. In the inelastic region where the J/ψ particles are produced via the photon–gluon fusion, $\gamma^* g \to J/\psi\ g$, the spin–dependent differential cross section is given by

$$\frac{d\Delta\sigma}{dx} = x\delta G(x, Q^2)\delta f(x, x_{min}) \ , \tag{5}$$

where $\delta G(x, Q^2)$ is the spin–dependent gluon distribution function and x the fraction of the proton momentum carried by the initial state gluon. δf is a function which is sharply peaked at x just above x_{min} and given by [4]

$$\begin{aligned} \delta f(x, x_{min}) \quad &= \quad \frac{16\pi\alpha_S^2\Gamma_{ee}}{3\alpha m_{J/\psi}^3}\frac{x_{min}^2}{x^2} \\ &\times \quad \left[\frac{x - x_{min}}{(x + x_{min})^2} + \frac{2x_{min}x\ln\frac{x}{x_{min}}}{(x + x_{min})^3} - \frac{x + x_{min}}{x(x - x_{min})} + \frac{2x_{min}\ln\frac{x}{x_{min}}}{(x - x_{min})^2}\right] \ , \end{aligned} \tag{6}$$

where $x_{min} \equiv m_{J/\psi}^2/s_T$ and $\sqrt{s_T}$ is the total energy in photon–proton collisions. Fig.3 shows the x dependence of $d\Delta\sigma/dx$ calculated with types of (a) and (b) for various energies including

relevant HERA energies. As δf has a sharp peak, the observed cross section $d\Delta\sigma/dx$ directly reflects the spin–dependent gluon distribution near x_{peak}. As is seen from eq.(5), $d\Delta\sigma/dx$ is linearly dependent on the spin–dependent gluon distribution. Thus, if $\delta G(x)$ is small or vanishing, $d\Delta\sigma/dx$ must be necessarily small. We are eager for the result given in Fig.3 being checked in the forthcoming experiments.

In summary, we have examined the effect of the gluon polarization on some physical quantities in special processes which are sensitive to the polarized gluon distribution. As for $A_{LL}^{J/\psi}(pp)$, there would be a good chance to find an evidence of largely polarized gluons in moderate p_T regions ($p_T > 1$GeV). Furthermore, since $d\Delta\sigma/dx$ for J/ψ leptoproductions is directly proportional to the polarized gluon distribution, one can easily examine the magnitude of the gluon polarization by measuring these quantities in experiments. The J/ψ productions in polarized ep and pp collisions considered here can therefore serve as a very clean probe of the polarized gluon distributions in a proton.

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Figure captions

Fig. 1: The x dependence of (A) $x\delta G(x,Q^2)$ and (B) $\delta G(x,Q^2)/G(x,Q^2)$ for various types (a)–(c) given by eqs.(1), (2) and (3) at $Q^2 = 10.7$ GeV^2.

Fig. 2: The two–spin asymmetries $A_{LL}^{J/\psi}(pp)$ for $\theta = 90^\circ$ calculated by using types (a), (b) and (c) as the spin–dependent gluon distribution functions, as a function of transverse momenta p_T of J/ψ at (A) $\sqrt{s} = 20$ GeV, and (B) $\sqrt{s} = 100$ GeV. The solid, dashed and dash–dotted curves correspond to types (a), (b) and (c), respectively. Q^2 is typically taken to be $m_{J/\psi}^2 + p_T^2$.

Fig. 3: The distribution $d\Delta\sigma/dx$ predicted by using types (a) and (b) of $x\delta G(x,Q^2)$, as a function of x for different values of $\sqrt{s_T}$. The solid (dashed) curve corresponds to type (a) ((b)).